Co-Electrolysis of Water and CO_2 for synthetic fuels

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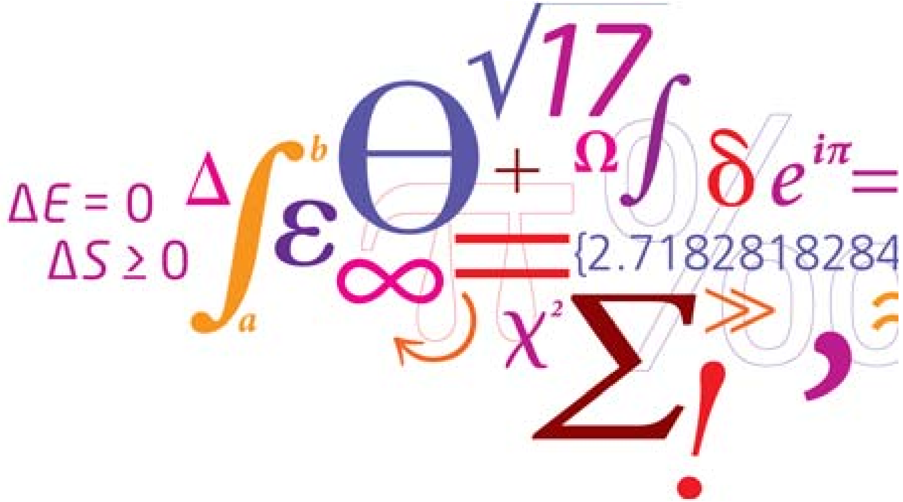


DTU Energy Conversion
Department of Energy Conversion and Storage

Outline

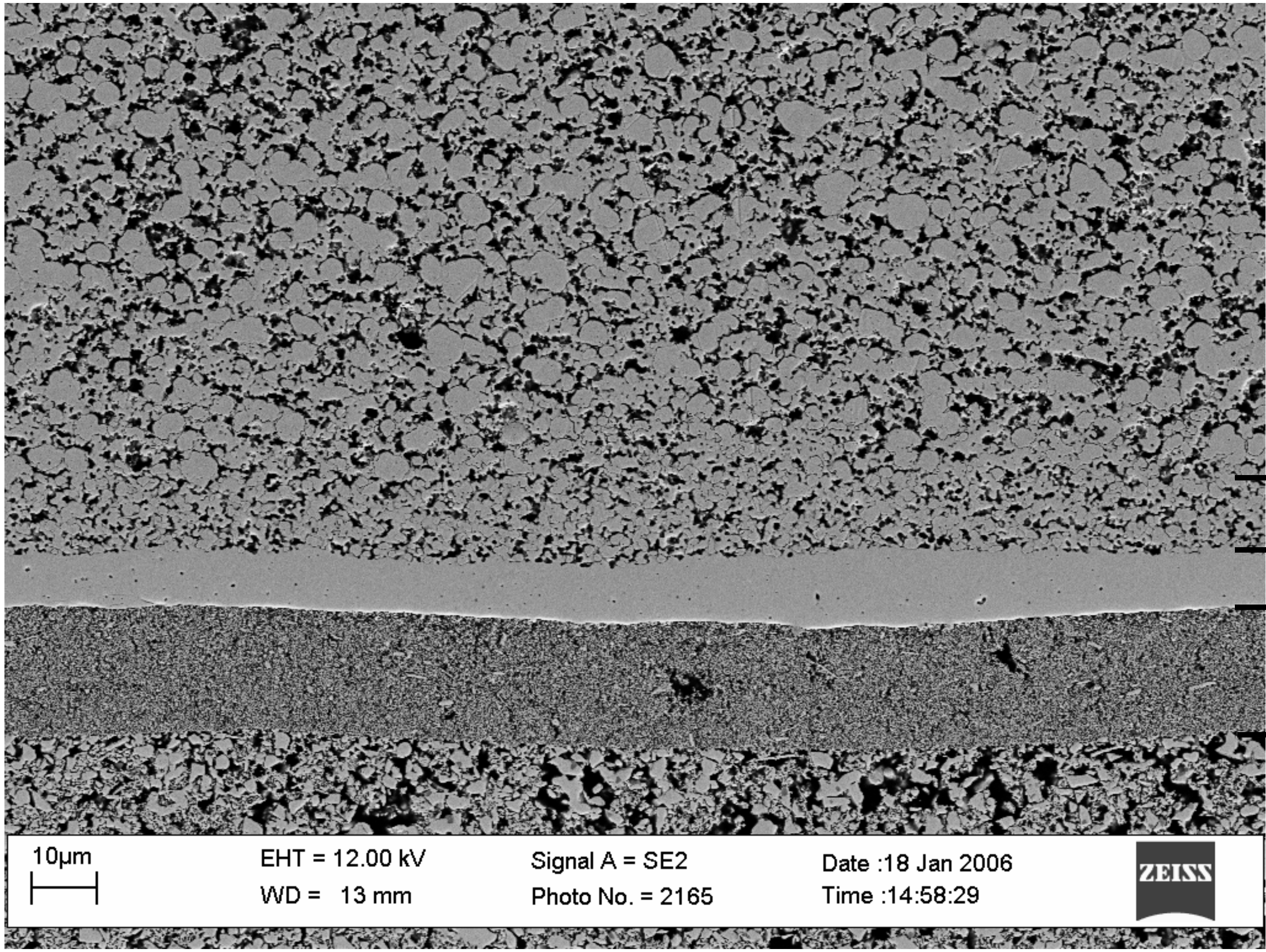
1. Solid Oxide Electrolyser Cell (SOEC)

2. SOEC Electrode Potentials, Thermodynamic

3. Gas Diffusion and Conversion

The Solid Oxide Cell

The Solid Oxide Cell



Ni-YSZ support & current collector

Ni-YSZ electrode

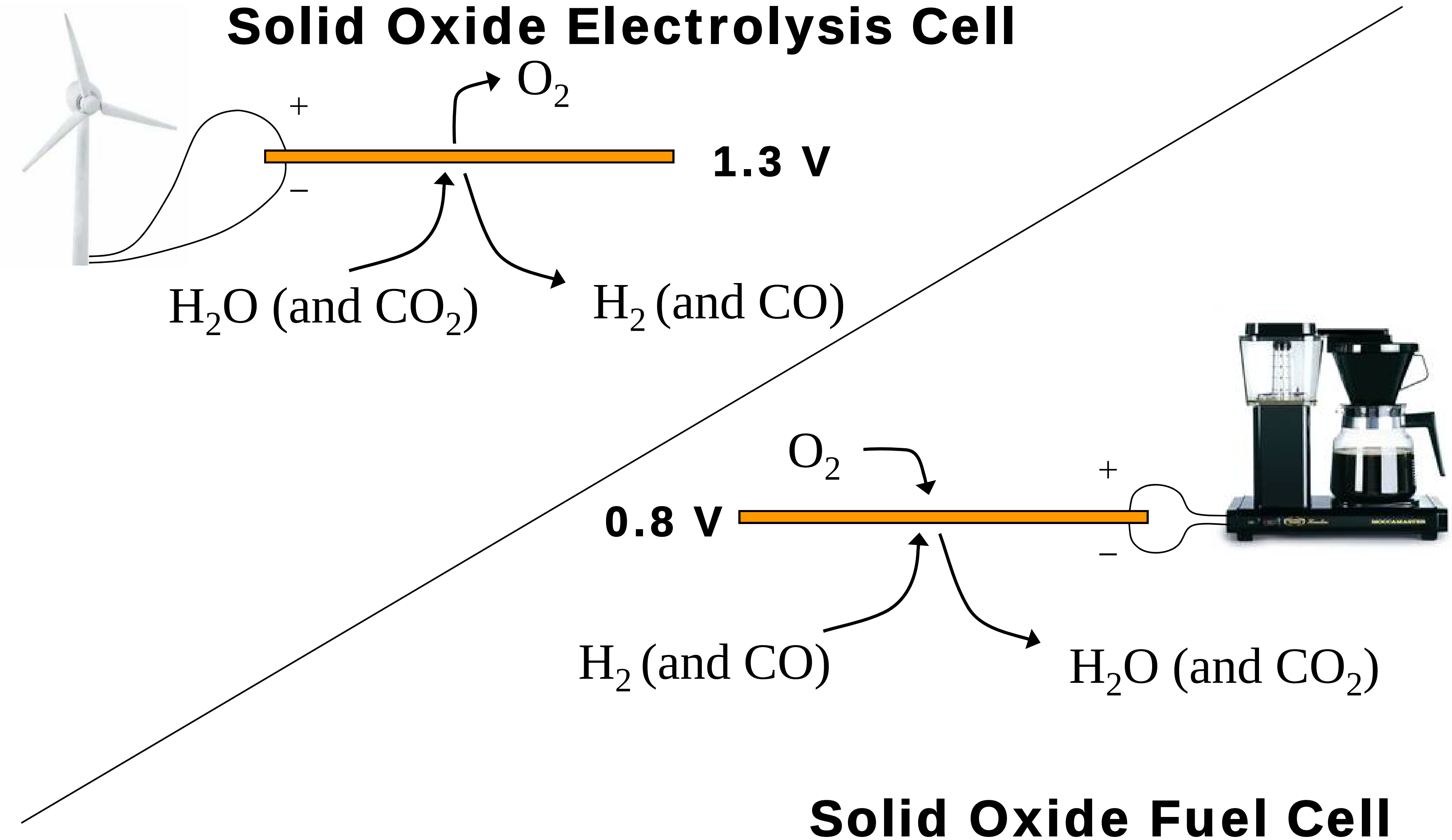
YSZ electrolyte

LSM-YSZ electrode

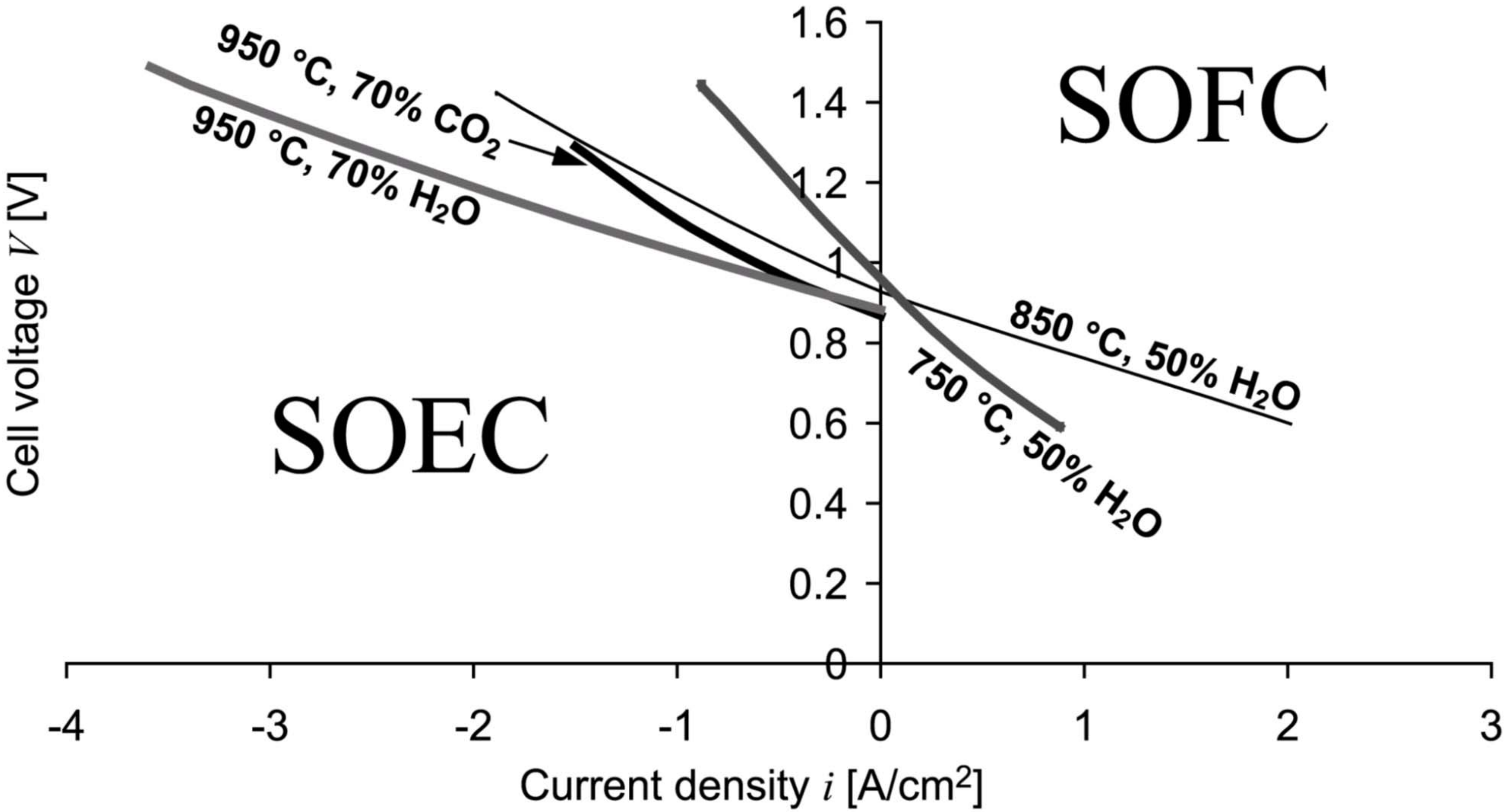
LSM current collector

LSM = $(La_{0.75}Sr_{0.25})_{0.95}MnO_3$ YSZ = $Zr_{0.84}Y_{0.16}O_{1.92}$

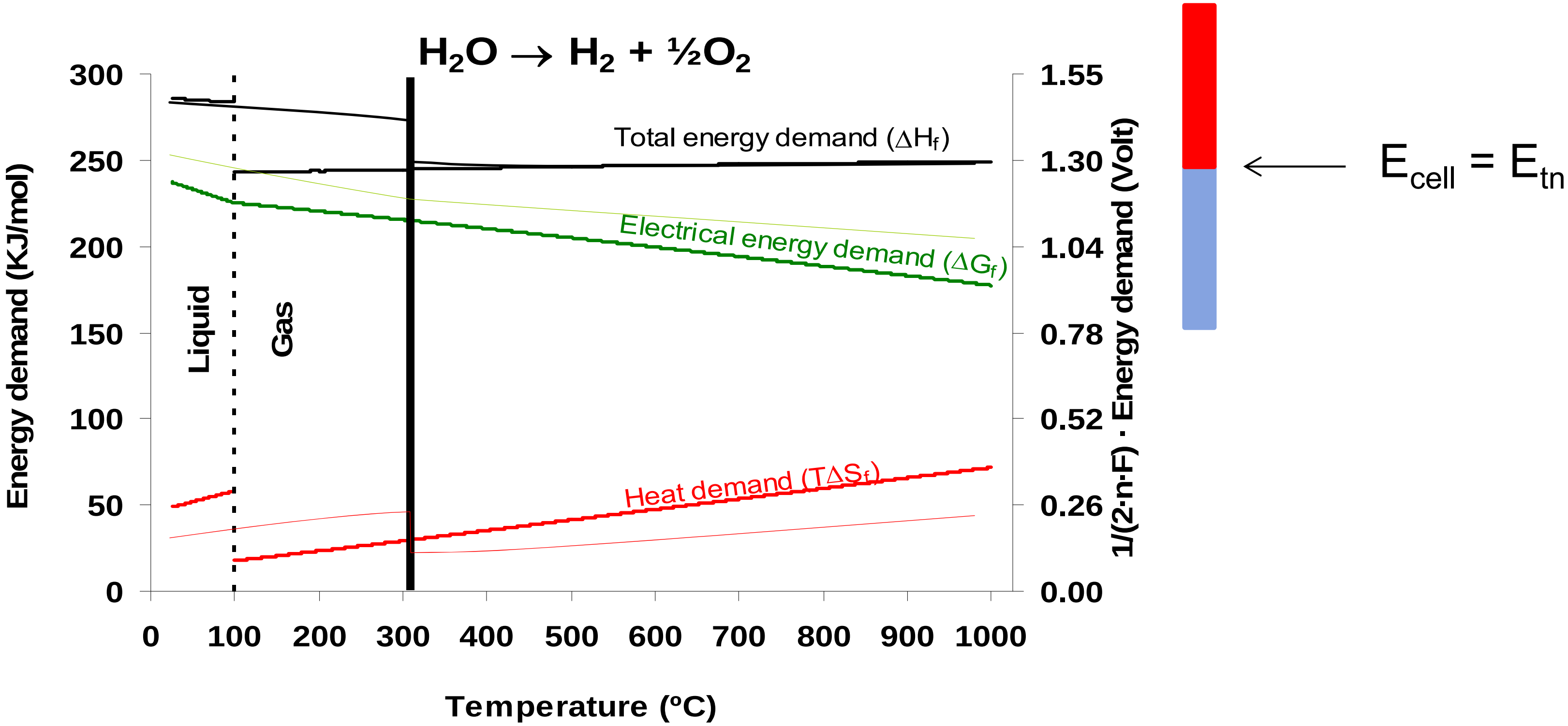
The Solid Oxide Cell



The Solid Oxide Cell

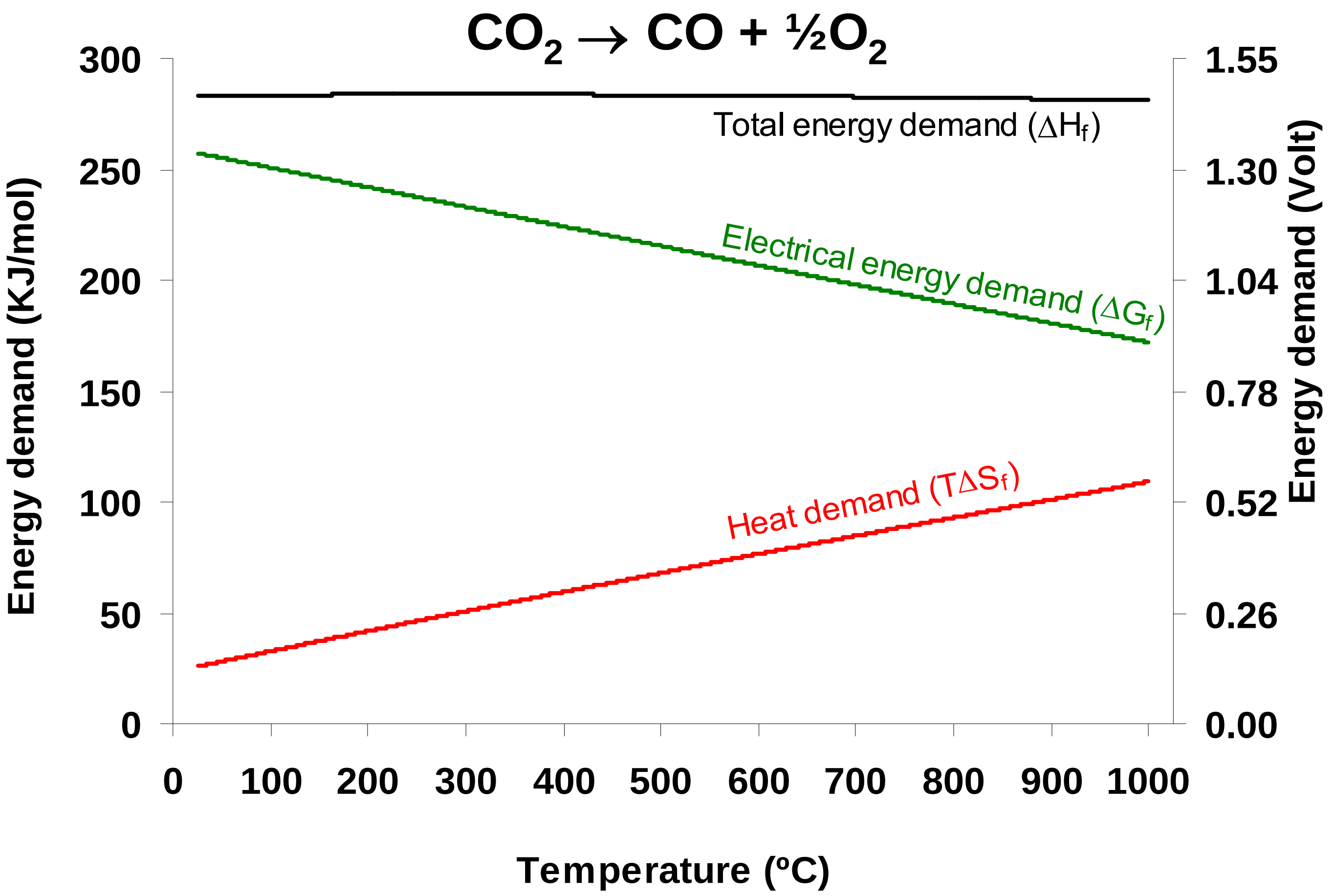


Thermodynamics

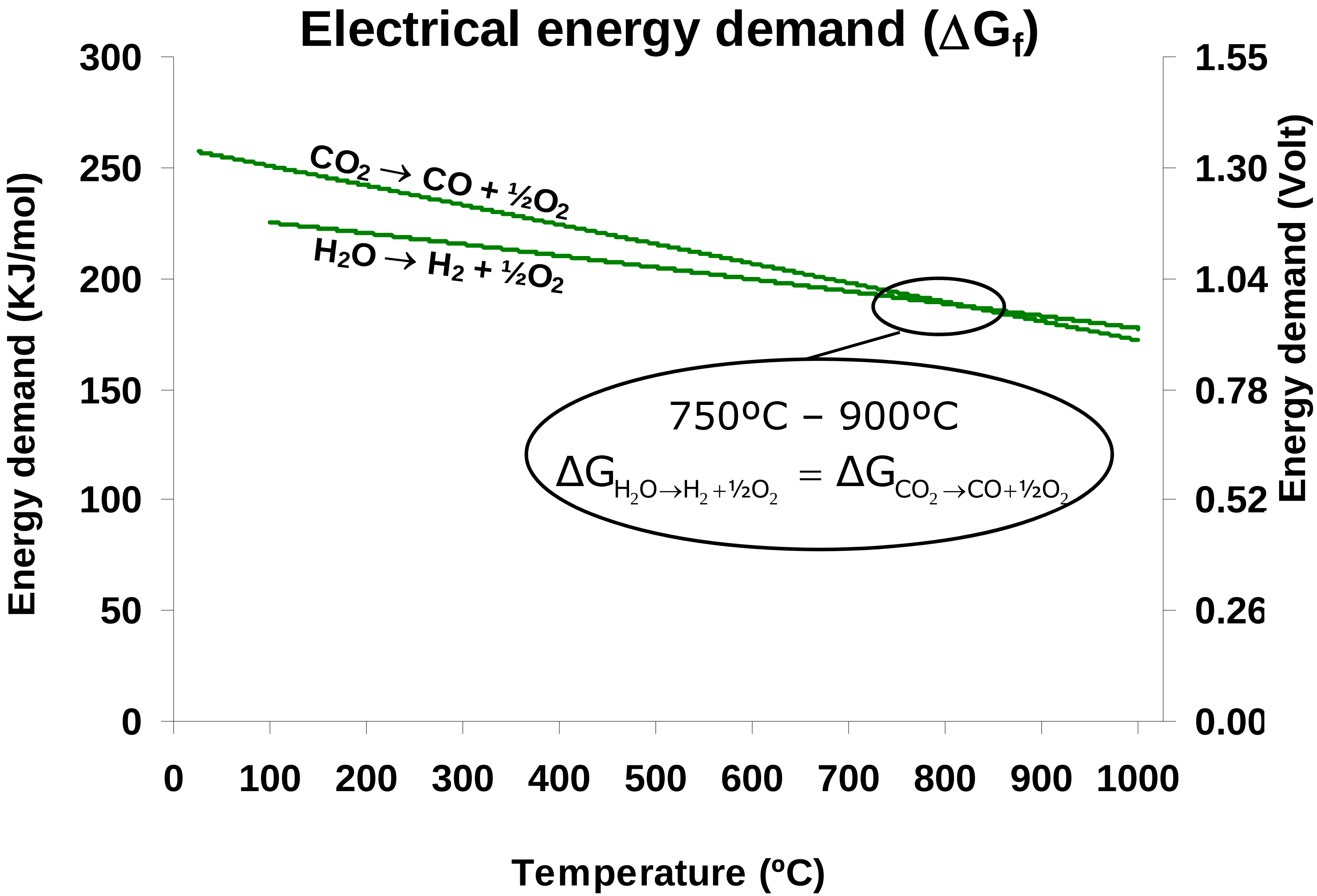


$\eta = 100\ \%$ at $E = E_{tn}$ (no heat loss)

Thermodynamics

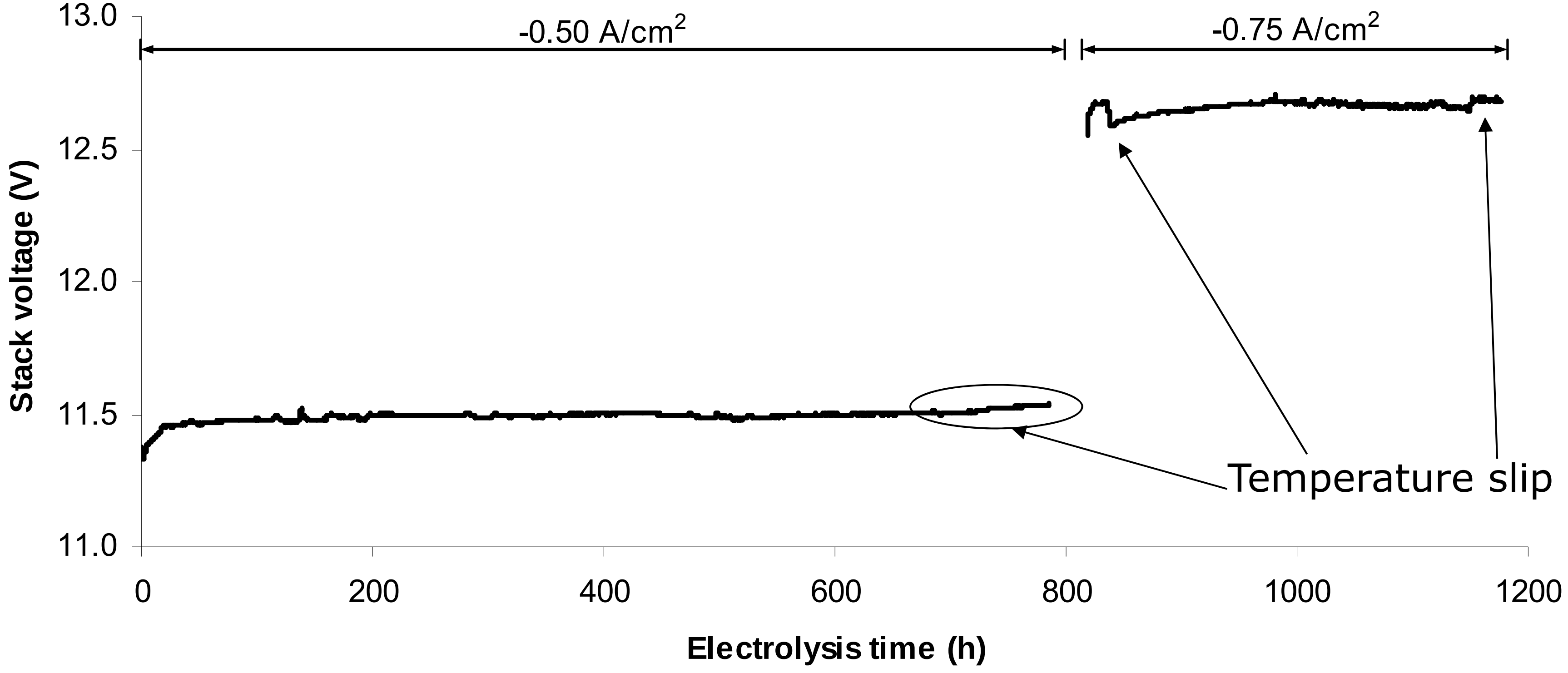


Thermodynamics



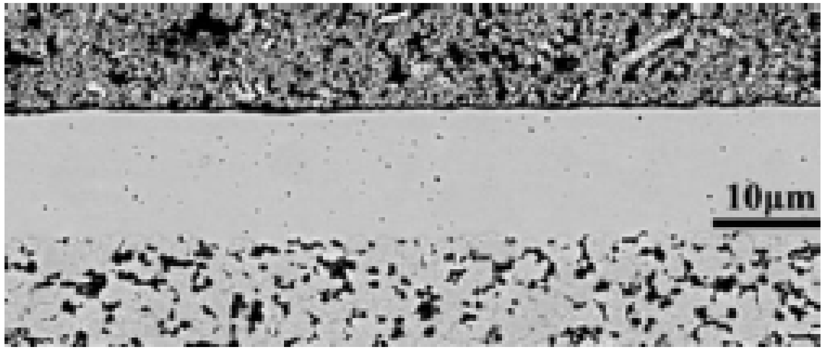
Co-electrolysis of H_2O and CO_2

1 kW - 10-cell stack – 12 × 12 cm^2
850 ºC, -0.50 (-0.75) A/cm^2, 45 % CO^2 / 45% H_2O / 10 % H_2

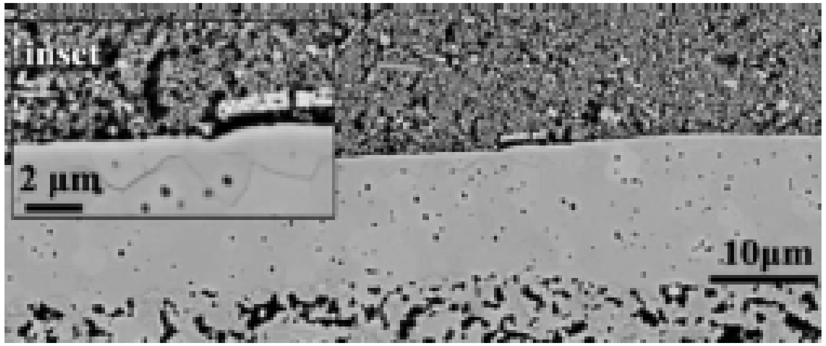


S. Ebbesen et al.

Electrolyte degradation at high current



Cell with R_s constant (-1 A/cm²)

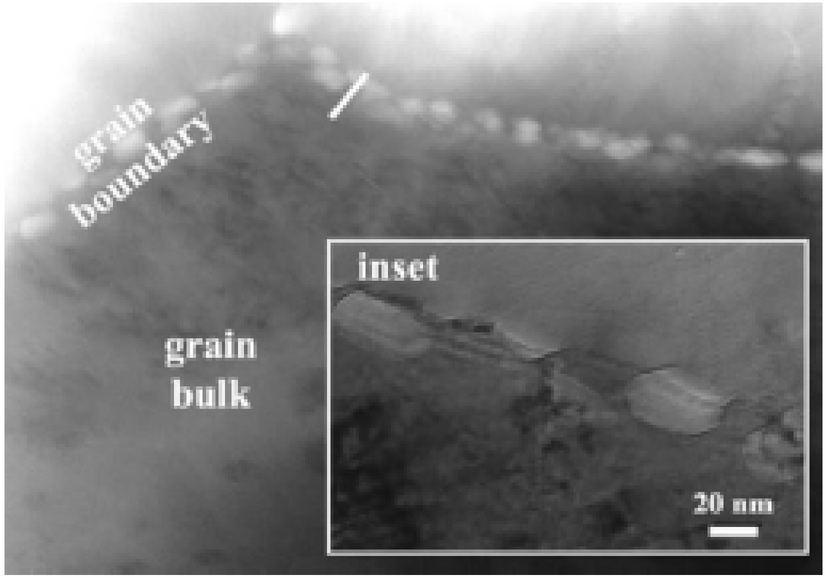


Cell with R_s increase (-2 A/cm²)

TEM study of the YSZ grain boundaries…. →

Ref. Knibbe et al., *J. Electrochem. Soc.*, **157**(8), B1209, 2010

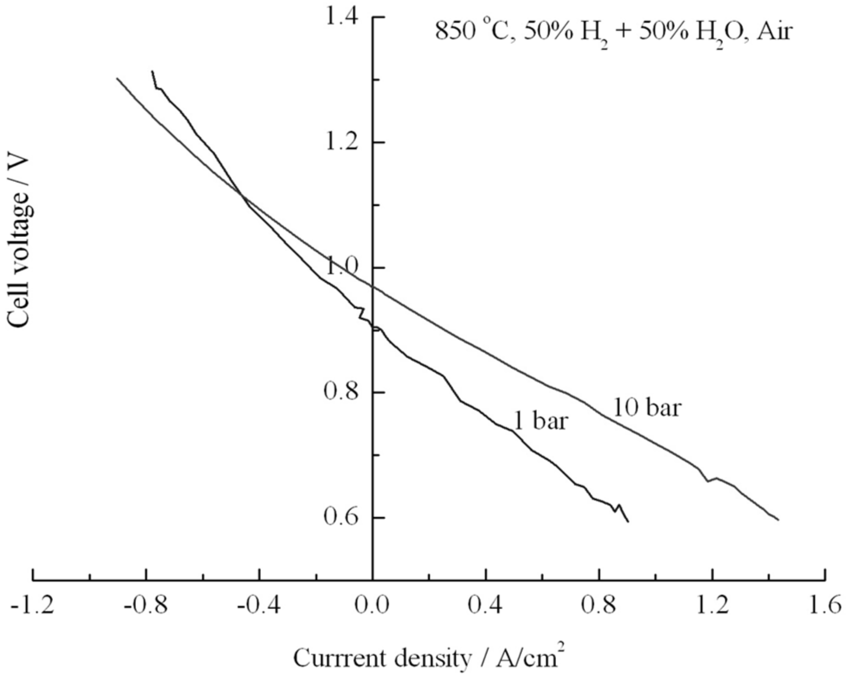
Electrolyte degradation at high current

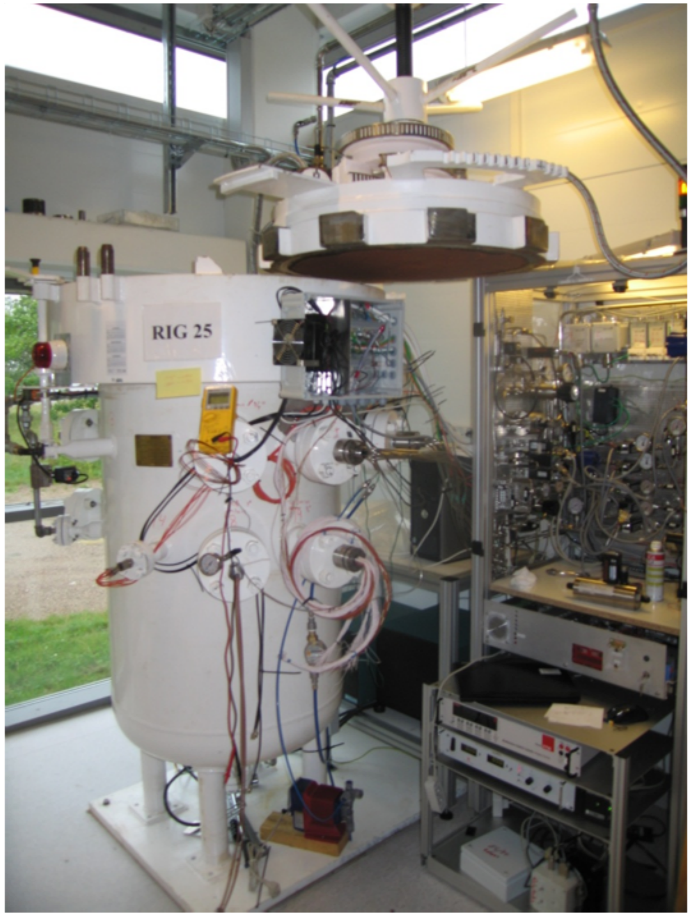


TEM of YSZ grain boundary near oxygen electrode from cell tested at -2 A/cm^2 (R_s increase)

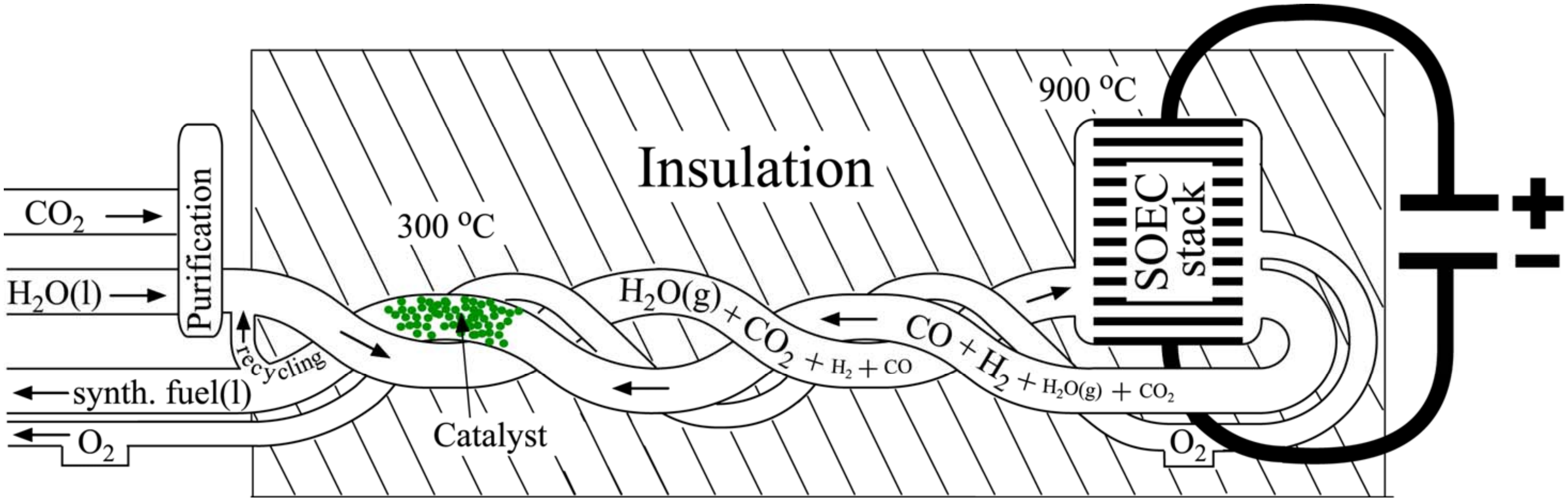
Pore / gaps inbetween YSZ grains in the YSZ close to the electrolyte – oxygen electrode interface observed.

The Pressure Test Setup

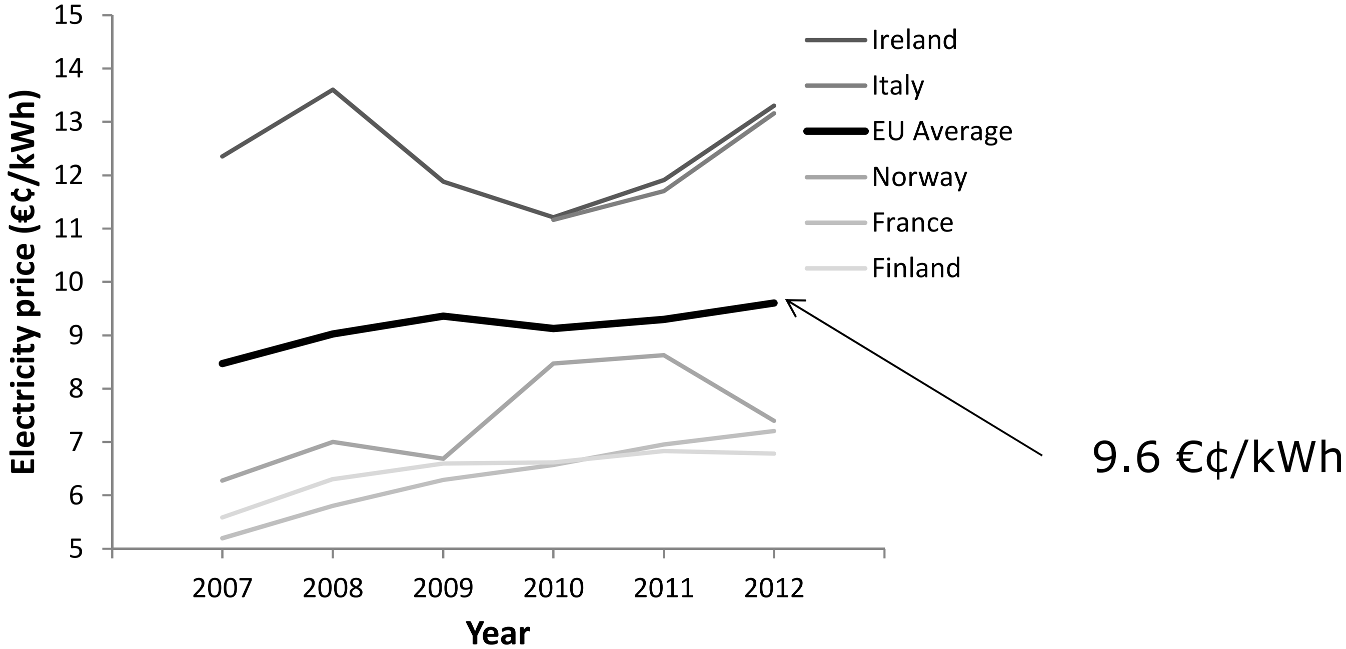




Synthetic Fuel Production

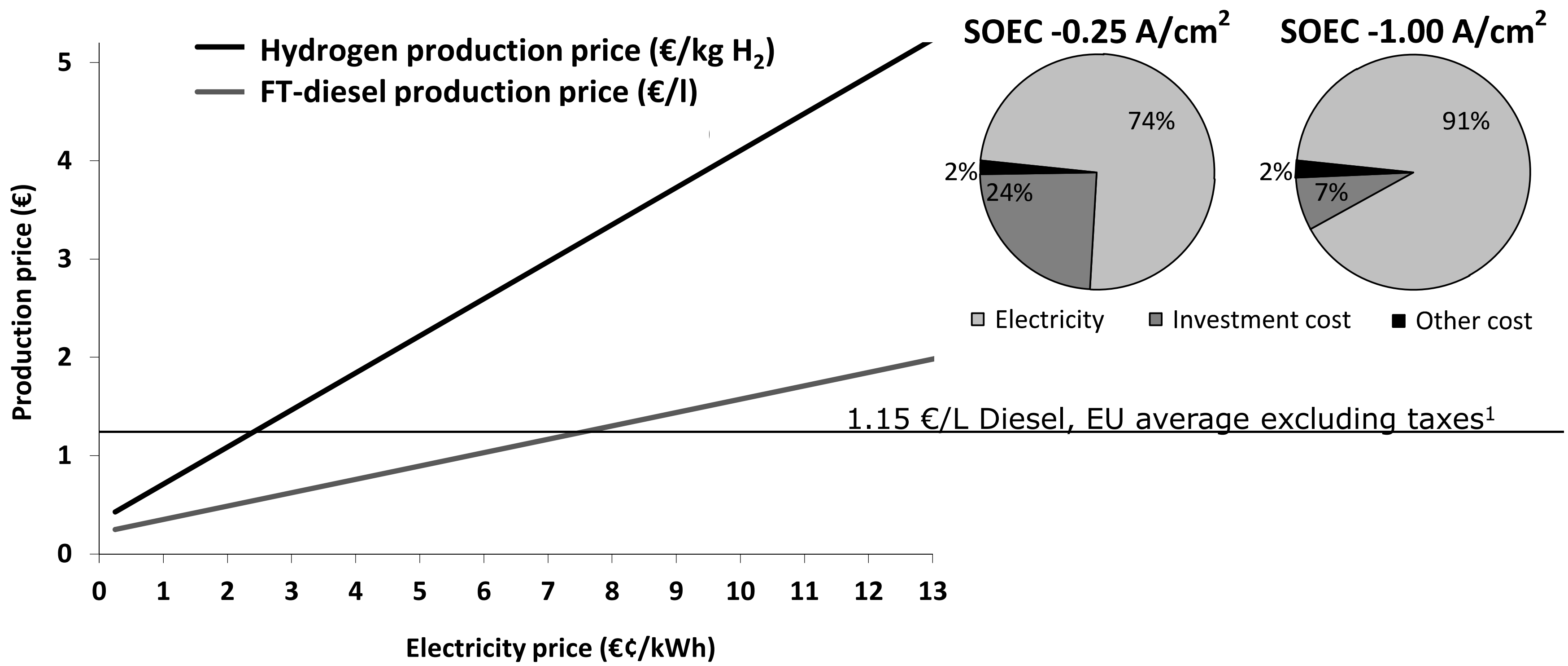


Synthetic Fuel Production Economy



S. D. Ebbesen, S. H. Jensen, A. Hauch and M. Mogensen, to be submitted

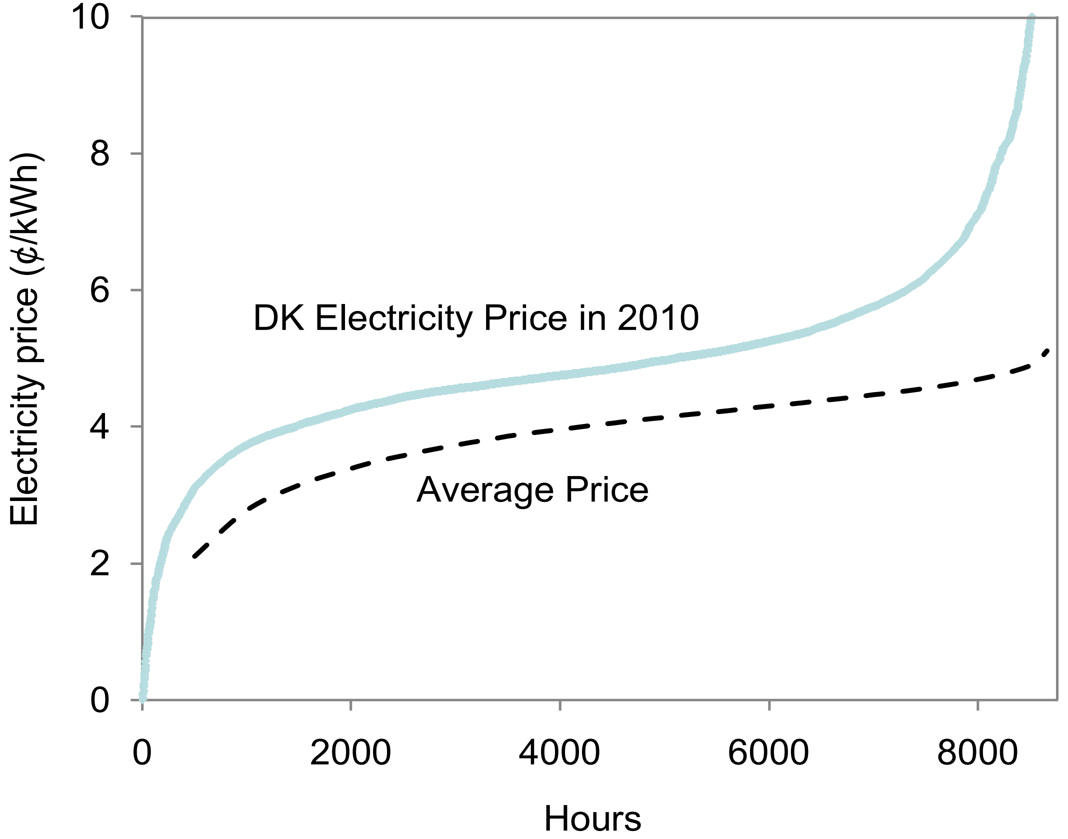
Synthetic Fuel Production Economy



[1]Europe's Energy Portal. http://www.energy.eu . 2013

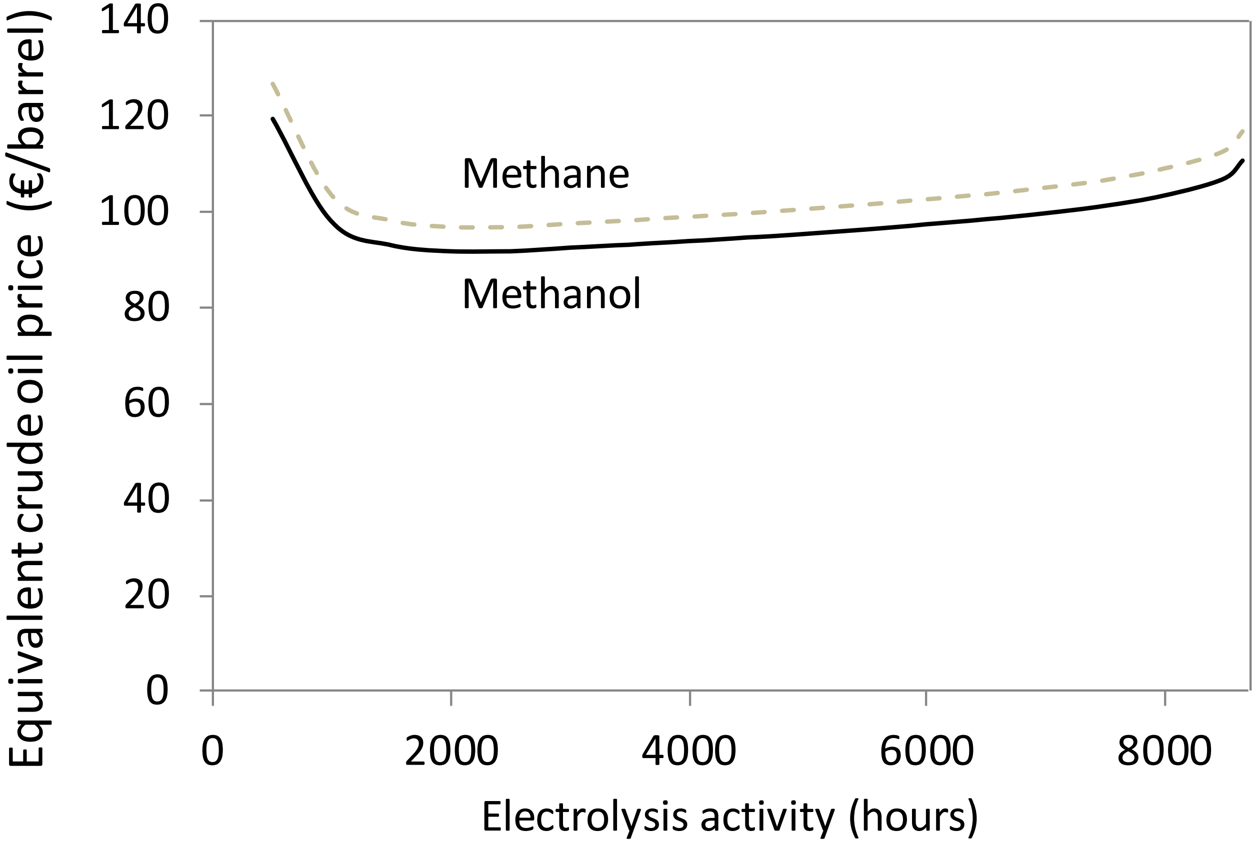
S. D. Ebbesen, S. H. Jensen, A. Hauch and M. Mogensen, to be submitted

SOC Economy



Electricity price (¢/kWh)
10
8
6
4
2
0
0
2000
4000
6000
8000
Hours
DK Electricity Price in 2010
Average Price

SOEC Economy



Søren Højgaard Jensen, Unpublished work

WTI and BRENT Crude Oil price

WTI

$/barrel

BRENT

$/barrel

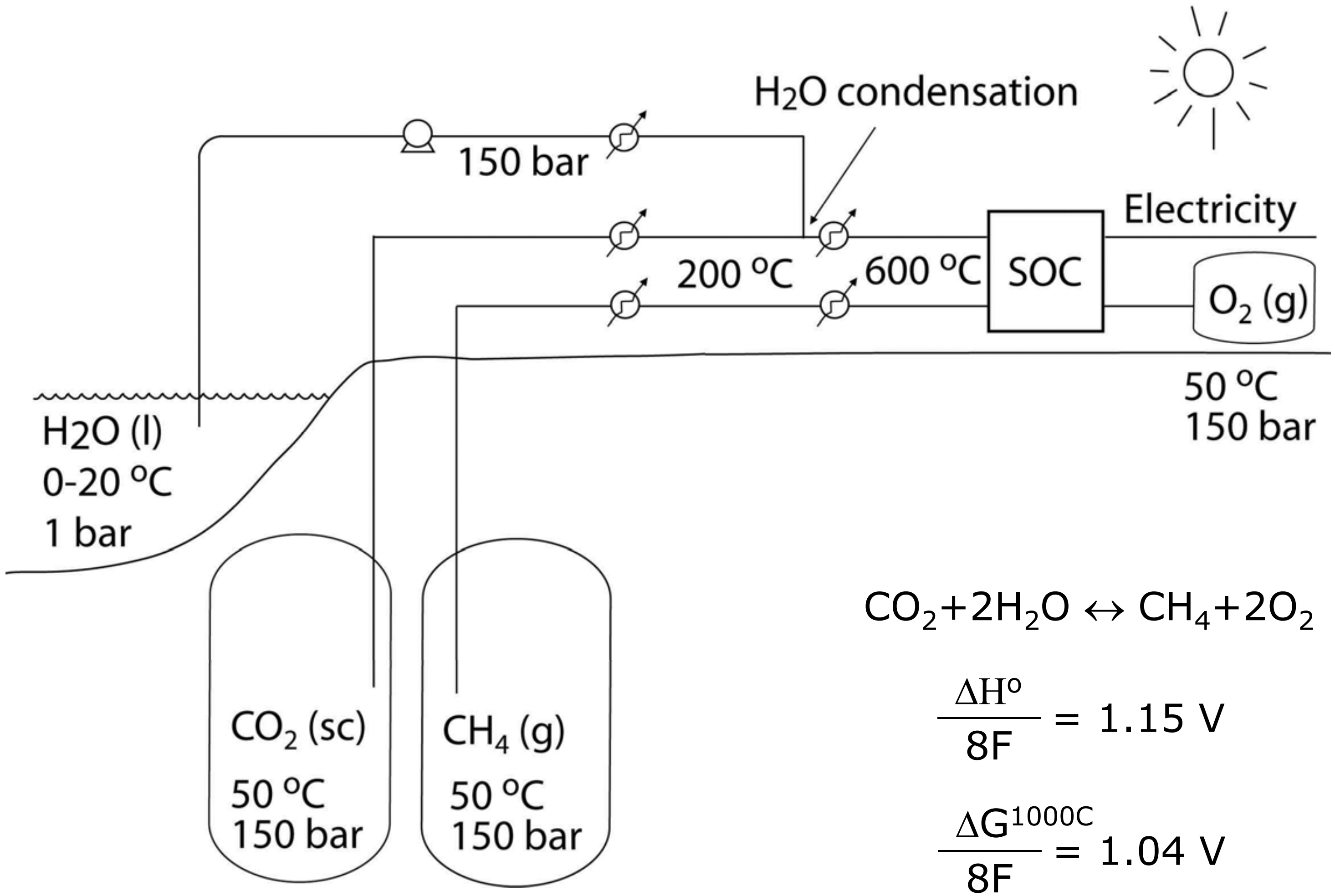
Conclusions

1. Stable co-electrolysis operation below -1 A/cm^2
2. Operation at high pressure makes internal catalysis possible which enables high production efficiency
3. Using Only Cheap Electricity Doesn’t change the synthetic fuel production costs significantly

Acknowledgement

I wish to thank Colleagues at DTU Energy Conversion for contributions to this presentation

Vision



$$CO_2 + 2H_2O \leftrightarrow CH_4 + 2O_2$$

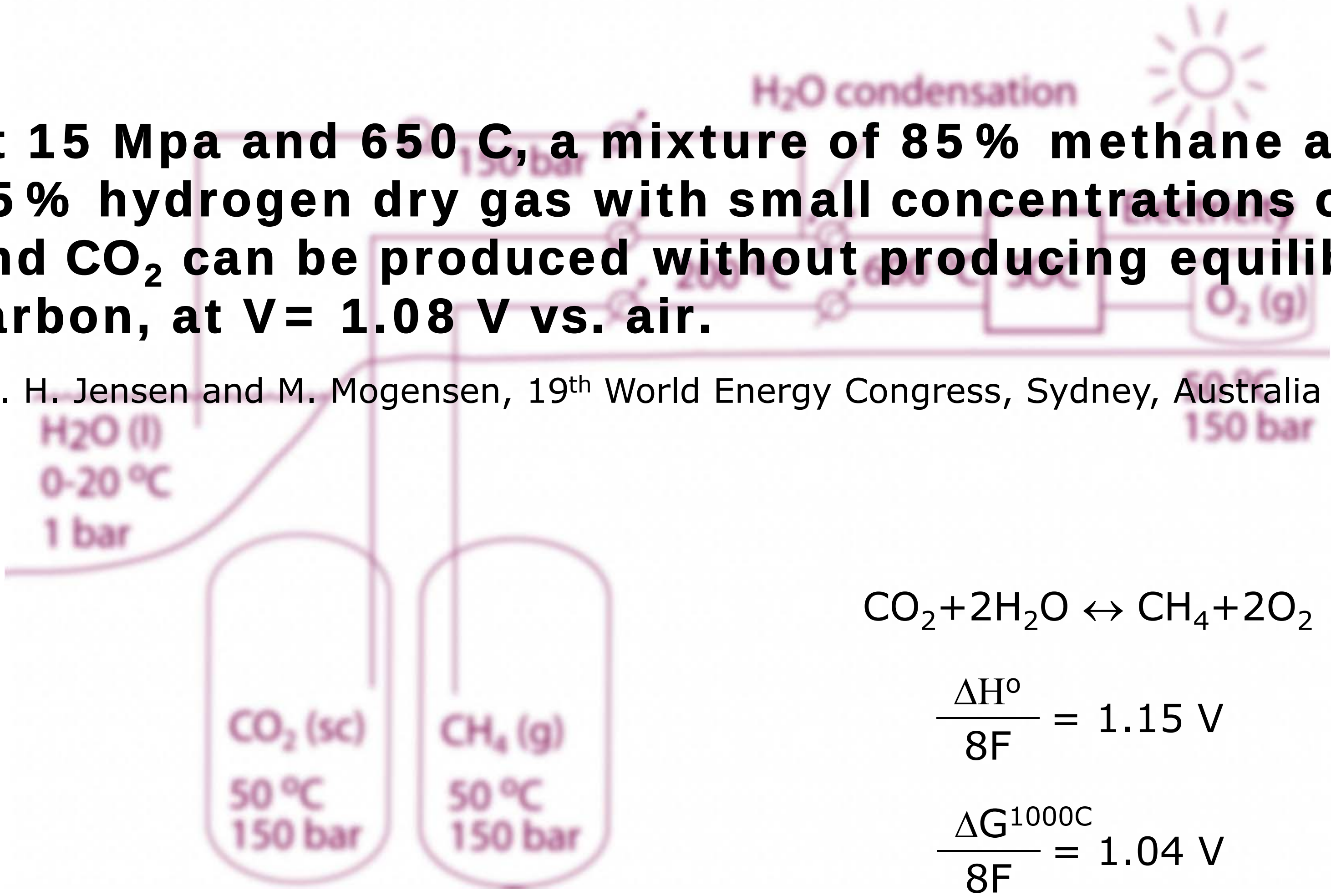
$$\frac{\Delta H^o}{8F} = 1.15\ V$$

$$\frac{\Delta G^{1000C}}{8F} = 1.04\ V$$

Vision

At 15 Mpa and 650 C, a mixture of 85% methane and 15% hydrogen dry gas with small concentrations of CO and CO_2 can be produced without producing equilibrium carbon, at V= 1.08 V vs. air.

S. H. Jensen and M. Mogensen, 19th World Energy Congress, Sydney, Australia 2004



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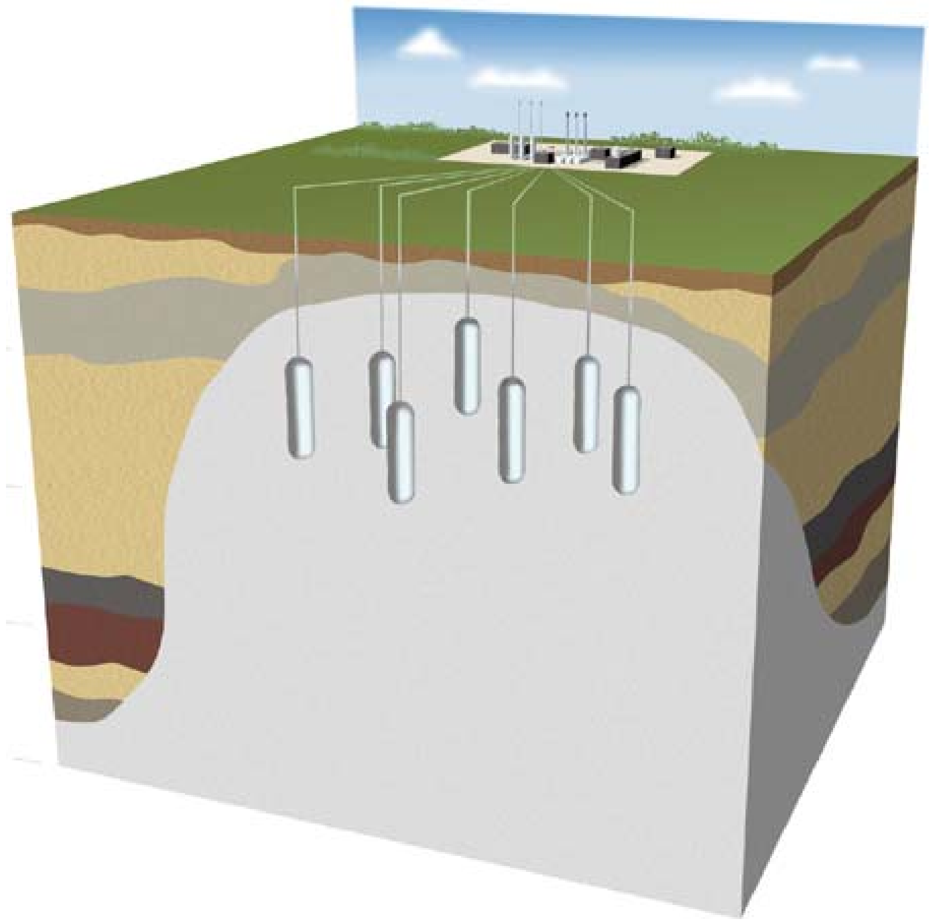
Vision

Ll. Thorup Salt caverns

- 150-200 bar
- 500 mill Nm^3 storage
- 5000 mill kWh stored
- 200 M€ CAPEX



Vision

Operating cost and conditions	
Operating pressure	150-200 bar
Storage capacity (volume)	500 Mio Nm^3
Storage capacity (Energy (CH_4))	5000 GWh
Cavern CAPEX (CH_4)	200 M€
Cavern CAPEX (CO_2 + CH_4)	0.08 €/kWh
Electrolysis/Fuel-cell operation/year	4000 hours
SOC cost	150 €/kW
Total SOC CAPEX	200 M€
Total system CAPEX	600 M€ (0.12 €/kWh)

Assume the return of investment on the storage facility is 5 years, the round trip efficiency is 70% and that the storage facility buys electricity during the summer (4000 h) at a cost of 9.6 €¢/kWh. Then the storage facility will be able to sell electricity during the winter periods (4000 h) for 14 €¢/kWh.